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THE EFFECT OF SIMULATED AERODYNAMIC HEATING ON THE STRENGTH OF --ETC(U)
JUN 76 G R RAMSDEN, D A HERRICK

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Technical Report No. 45

The Effect of Simulated Aerodynamic Heating on the Strength of Three Rocket Motor Case Steels

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THE EFFECT OF SIMULATED AERODYNAMIC HEATING ON THE STRENGTH OF THREE ROCKET MOTOR CASE STEELS.

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SUMMARY

The effect of simulated aerodynamic heating on the strength of three high strength steels used in rocket motor cases was investigated. Low alloy steel RS 131 (1% Cr-Mo) and 18% Ni maraging steels DTD 5212 and RPE 1090 (G 125) were tested at temperatures up to 700°C attained in 5 seconds. deg

The results show that the reduction in short term strength of these metals at elevated temperatures is not so great as to preclude their use in Mach 3 missiles and in some types of Mach 4 missiles.

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CONTENTS

1 INTRODUCTION

Missiles in flight are subjected to aerodynamic heating which causes a rise in skin temperature and consequent loss of strength in the motor case material. To evaluate this effect a research programme was carried out at the RPE in which metallic specimens were subjected to simulated aerodynamic heating at temperatures and for durations consistent with missile requirements. In the first stage several high strength aluminium alloys of possible use on Mach 2 to 3 missiles were investigated[1,2]. This report describes further work on three high strength steels, RS 131, DTD 5212 and RPE 1090 (G 125), relevant to Mach 3 to 4 missiles.

2 AERODYNAMIC HEATING EFFECT

The magnitude and duration of the aerodynamic heating effect depend on the flight envelope of the missile. To estimate typical temperatures and durations for the purpose of formulating the laboratory simulation experiments, the effects of Mach number, altitude, and position along the length of the motor body were examined using the iterative procedure described previously[1].

From these data it was decided that the test programme should cover the temperature range from 300°C to 700°C. The required surface temperature was to be attained in 5 seconds and tests were to be carried out, a) immediately after the temperature was reached, b) after 30 seconds at that temperature. These times represented the two main flight conditions: a) the initial boost phase when the motor case is highly stressed, b) the sustain and free flight phase when the stresses in the case are generally less, (depending on the amount of lateral acceleration imposed by manoeuvring).

3 EXPERIMENTAL PROCEDURE

3.1 Test programme

The variables investigated were:

i) 3 materials;

ii) 3 temperatures: 300°C, 500°C and 700°C;

iii) times of 0 sec and 30 sec at the test temperature before testing;

iv) orientation of the specimen in the billet - longitudinal specimens of all 3 materials, and transverse specimens of 1 material were tested.

At the end of the programme a limited number of tests was carried out to examine the effect of strain rate on the stress/strain curve.

3.2 Test specimens

Small cylindrical test specimens of the dimensions given in Fig. 1 were used.

3.3 Materials

3.3.1 RS 131 is a weldable 1 per cent chromium-molybdenum high strength (75 ton) steel, widely used in UK rocket motor cases. Its specified chemical composition and mechanical properties are given in Table 2a. The specimens were rough machined from a hot rolled slab in both longitudinal and transverse directions, oil quenched from 900°C, tempered at 480°C for 1 hour, and finally machined.

3.3.2 DTD 5212 is a 115 ton maraging steel which has been used for rocket motor cases. Its specified chemical composition and mechanical properties are given in Table 2b. The specimens were machined in the longitudinal direction from solution treated bar and maraged at 480°C for 3 hours.

3.3.3 RPE 1090 (G 125) is a 130 ton maraging steel under assessment for rocket motor cases. Its specified chemical composition and mechanical properties are given in Table 2c. The specimens were machined in the longitudinal direction from solution treated bar and maraged at 485°C for 6 hours.

3.4 Testing technique

3.4.1 Heating method

The temperatures required were several hundred degrees above the capabilities of the radiation furnace used for tests of aluminium[1] and as steels are well suited to heating by induction this method was chosen. A Stanelco Hyforce 6 kW generator was used, with a single-turn coil consisting of a sheet of copper encircling the gauge length of the specimen, (see Fig. 3). This type of construction, although presenting electrical matching difficulties, gave the most uniform heating along the length of the specimen. It was also sufficiently rigid and robust to operate in the vertical position and to avoid damage by handling during insertion of the specimen. The tubes seen soldered to the sheet in Fig. 3 are coolant water tubes and are not part of the inductive circuit.

3.4.2 Temperature measurement and control

Temperature was measured by an Ircon model 300C infrared pyrometer (accuracy 2%) sighted through a small hole drilled in the copper sheet, and recorded on a Bryans 20180/S XY/T plotter (accuracy 2%). The pyrometer also controlled the induction power supply through a feed-back loop.

The temperature ranges recorded during the tests were 300-308°C, 500-510°C and 700-710°C.

3.4.3 Test procedure

Tensile loading was by a standard Instron 10000 kg testing machine, model 1115-A3, following the procedure established during tests on aluminium[1,2].

The desired temperature was reached in 5 seconds and testing was commenced either at once, for the immediate tests, or after a further 30 seconds for the delayed tests. The strain rate was 4.2×10^{-3} sec^{-1} up to the 0.5 per cent proof stress, and then 4.2×10^{-2} sec^{-1} to fracture to complete the test rapidly and minimise the effect of any temperature drift. A typical Instron record of load against crosshead movement is shown in Fig. 4. The tensile properties were derived directly from these records, i.e. no extensometer was used. It has been shown[3] that the errors in proof stress values obtained by this direct conversion of crosshead movement into strain are less than 2 per cent on a "hard" testing machine such as the Instron. Elongation values were derived from measurements made on the specimens before and after testing.

4 RESULTS

The complete results for the materials: RS 131 longitudinal, RS 131 transverse, DTD 5212, and RPE 1090 are given in Tables 3a, 3b, 3c and 3d respectively. The principal results are shown in graphical form in Figs 5 to 8.

4.1 Effect of strain rate

As explained in Section 3.4.3, to complete the test rapidly the strain rate was increased by a factor of ten during the test, giving the record shown in Fig. 4. The value of UTS from this record is given in column 8 of Tables 3a to 3d. Since a strain rate of 4.2×10^{-2} sec^{-1} may be rather fast for general application an attempt was made by geometrical construction on the records to estimate the UTS value corresponding to the lower initial rate. The estimated values are given in column 7 of Tables 3a to 3d. A few comparative tests showed that these tend to be lower than the values from a low strain rate test, but they have nevertheless been preferred for use in the graphs of Figs 5 to 8.

For the maraging steels the difference in UTS due to strain rate is negligible at room temperature, 300°C and 500°C, and small at 700°C. For RS 131 the difference is small at room temperature, 300°C and 500°C, but considerable at 700°C.

4.2 Effect of temperature

Tensile properties decrease considerably with increasing test temperature, as shown in Tables 3a to 3d and in Figs 5 to 8. The UTS is about 65 per cent of the room temperature strength at $500^{o}C$ for all the materials, and thereafter falls rapidly to a very low figure at $700^{o}C$. At $300^{o}C$, however, RS 131 maintains a higher proportion of its room temperature strength (about 94 per cent) than do DTD 52.2 (about 81 per cent) and RPE 1090 (about 84 per cent).

4.3 Proof stress

In RS 131 the gap between UTS and 0.2 proof stress is maintained at $300^{o}C$ and then steadily diminishes up to $500^{o}C$ (see Figs 5 and 6) during which ductile fracture occurs. With the two maraging steels the gap is small at all temperatures.

4.4 Effect of time

The results for tests carried out immediately after the test temperature was reached (5 seconds) and those after a stay of 30 seconds at the temperature (5 + 30 seconds) are shown in Tables 3a to 3d. In all cases the difference in strength is negligible.

4.5 Effect of orientation

The results for RS 131 in the longitudinal direction are given in Table 3a and Fig. 5; and in the transverse direction in Table 3b and Fig. 6. The difference in values is very small. As expected, strength and ductility in the transverse direction are lower.

5 CONCLUSIONS

Of the variables investigated only temperature has any significant effect. The effects of time at temperature, and of orientation are negligible, as is that of strain rate within the practicable temperature range.

The results indicate that the low alloy steel RS 131 and the maraging steels DTD 5212 and RPE 1090 (G 125) can be considered for all Mach 3 missiles, and in certain flight envelopes for Mach 4 missiles.

6 REFERENCES

No.	Authors	Title, etc.
1	Midgley, P. Ramsden, G.R. Herrick, D.A.R.	The effect of simulated aerodynamic heating on the strength of L65 aluminium alloy. Rocket Propulsion Establishment Tech. Report No. 27 (1974)
2	Midgley, P. Ramsden, G.R. Herrick, D.A.R.	The effect of simulated aerodynamic heating on the strength of DTD 5044 and DTD aluminium alloys. RPE Tech. report in preparation.
3	Forrest, P.G. Armstrong, K.B.	A note on the accuracy of proof stress measurements without an extensometer. Machines for materials and environmental testing. Inst. Mech. Eng., London, 1966

TABLE 1a

Calculated skin temperatures in K, (^{o}C) for a steel case 3.3 mm (0.13 inch) thick, at a point 1.8 m (6 ft) behind the stagnation point, at Mach 3

Time in seconds	Altitude in metres (feet)						
	0 (0)	610 (2000)	1525 (5000)	3050 (10000)	6100 (20000)	9150 (30000)	15250 (50000)
0	288	284	278	268	248	229	217
	(15)	(11)	(5)	(-5)	(-25)	(-44)	(-57)
1	637	620	594	551	468	390	302
	(364)	(347)	(321)	(278)	(195)	(117)	(29)
2	720	705	683	643	560	475	362
	(447)	(432)	(410)	(370)	(287)	(202)	(89)
3	744	732	712	679	605	523	407
	(471)	(459)	(439)	(406)	(332)	(250)	(134)
4	752	740	723	693	627	552	441
	(479)	(467)	(450)	(420)	(354)	(279)	(168)
5	754	743	727	699	639	570	467
	(481)	(470)	(454)	(426)	(366)	(297)	(194)
6	755	744	729	701	645	581	488
	(482)	(471)	(456)	(428)	(372)	(308)	215
8	755	745	729	703-	649	592	516
	(482)	(472)	(456)	(430)	(376)	(319)	(243)
10	755	745	729	703	65	596	535
	(482)	(472)	(456)	(430)	(378)	(323)	(262)

TABLE 1b

Skin temperature for the same case at Mach 4

Time in seconds	Altitude in metres (feet)						
	0 (0)	610 (2000)	1525 (5000)	3050 (10000)	6100 (20000)	9150 (30000)	15250 (50000)
0	288	284	278	268	248	229	217
	(15)	(11)	(5)	(-5)	(-25)	(-44)	(-57)
1	921	894	854	787	655	532	380
	(648)	(621)	(581)	(514)	(382)	(259)	(107)
2	1060	1037	1002	942	813	678	490
	(787)	(764)	(729)	(669)	(540)	(405)	(217)
3	1100	1081	1052	1001	887	760	569
	(827)	(808)	(779)	(728)	(614)	(487)	(296)
4	1112	1096	1070	1025	924	809	628
	(839)	(823)	(797)	(752)	(651)	(536)	355
5	1116	1100	1076	1034	943	838	673
	(843)	(827)	(803)	(761)	(700)	(565)	(400)
6	1117	1102	1078	1038	953	857	707
	(844)	(829)	(805)	(765)	(680)	(584)	(434)
8	1118	1103	1080	1041	961	875	756
	(845)	(830)	(807)	(768)	(688)	(602)	(483)
10	1118	1103	1080	1041	964	883	786
	(845)	(830)	(807)	(768)	(691)	(610)	(513)

TABLE 2

Specified composition and properties

(a) RS 131

Composition:	min %	max %
Carbon	0.30	0.35
Manganese	0.40	0.60
Silicon	0.10	0.35
Sulphur	-	0.010
Phosphorus	-	0.015
Nickel	-	0.30
Chromium	0.80	1.10
Molybdenum	0.15	0.25

Properties: (room temperature)

UTS (min)	1158 MNm^{2} (75 $tonf/in^{2}$)
0.1% proof stress (min)	1004 MNm^{2} (65 $tonf/in^{2}$)
Elongation (min)	8%

(b) DTD 5212

Composition:	min %	max %
Carbon	-	0.015
Silicon	-	0.10
Manganese	-	0.10
Phosphorus	-	0.010
Sulphur	-	0.010
Aluminium	0.05	0.15
Chromium	-	0.25
Cobalt	7.0	8.5
Nickel	17.0	19.0
Molybdenum	4.6	5.2
Titanium	0.30	0.60

Properties: (room temperature)

UTS (min)	1800 MNm^{2} (116 $tonf/in^{2}$)
UTS (max)	2000 MNm^{2} (130 $tonf/in^{2}$)
0.2% proof stress (min)	1700 MNm^{2} (110 $tonf/in^{2}$)
Elongation (min)	8%

(c) RPE 1090 (G 125)

Composition:	min	max
Carbon	-	0.010%
Manganese	-	0.10
Silicon	-	0.10
Phosphorus	-	0.010
Sulphur	-	0.010
Chromium	-	0.10
Aluminium	0.05	0.15
Cobalt	8.5	9.5
Molybdenum	4.6	5.2
Nickel	17.0	19.0
Titanium	0.60	0.90

Properties: (room temperature)

UTS (min)	2000 MNm^{2} (130 $tonf/in^{2}$)
UTS (max)	2240 MNm_{2} (145 $tonf/in_{2}$)
0.2% proof stress (min)	1930 MNm^{2} (125 $tonf/in^{2}$)
Elongation (min	7%

TABLE 3

Tensile properties

(a) RS 131 Longitudinal

Temperature ^{o}C	Time sec	Sample No.	0.1% proof stress MNm^{-2}	0.2% proof stress MNm^{-2}	0.5% proof stress MNm^{-2}	UTS slow $(0.0042\ sec^{-1})$ Strain rate MNm^{-2}	UTS fast $(0.042\ sec^{-1})$ Strain rate MNm^{-2}	Elongation %
R.T.		L1	1147	1168	1204	1229	1263	10.1
		L2	1149	1168	1202	1224	1261	11.4
		AV	1148	1168	1203	1227	1262	10.8
300	5	L3	1036	1063	1116	1147	1188	11.6
	"	L4	1024	1062	1024	1146	1187	10.5
		AV	1030	1063	1120	1147	1188	11.1
	5 + 30	L6	1044	1076	1122	1173	1194	11.1
	"	L7	1062	1084	1128	1167	1194	11.2
		AV	1053	1080	1125	1170	1194	11.2
500	5	L8	773	794	805	805	831	8.7
	"	L9	768	783	796	796	811	9.2
		AV	771	789	801	801	821	9.0
	5 + 30	L10	769	784	796	796	813	9.6
	"	L11	759	778	795	795	800	9.2
		AV	764	781	796	796	807	9.4
700	5	L13	150	161	174	179	230	14.0
	"	L14	150	167	180	186	234	15.4
		AV	150	164	177	183	232	14.7
	5 + 30	L15	154	163	177	181	223	14.3
	"	L16	156	165	178	180	220	15.5
		AV	155	164	178	181	222	14.9

TABLE 3 (contd)

(b) RS 131 Transverse

Temperature ^{o}C	Time sec	Sample No.	0.1% proof stress MNm^{-2}	0.2% proof stress MNm^{-2}	0.5% proof stress MNm^{-2}	UTS slow ($0.0042\ sec^{-1}$) Strain rate MNm^{-2}	UTS fast ($0.042\ sec^{-1}$) Strain rate MNm^{-2}	Elongation %
		T1	1136	1155	1188	1222	1242	8.5
		T2	1141	1163	1193	1219	1246	9.0
		AV	1139	1159	1191	1221	1244	8.8
300	5	T3	1047	1072	1119	1171	1189	7.6
	"	T4	1053	1076	1123	1138	1180	8.4
		AV	1050	1074	1121	1155	1185	8.0
	5 + 30	T5	1024	1062	1110	1157	1178	7.9
	"	T28	1067	1094	1128	1167	1180	6.1
		AV	1046	1078	1119	1162	1179	7.0
500	5	T7	786	803	814	814	827	7.6
	"	T8	775	791	805	805	832	7.3
		AV	781	797	810	810	830	7.5
	5 + 30	T11	763	769	775	775	797	8.4
	"	T12	764	781	795	795	803	8.2
		AV	764	775	785	785	800	8.3
700	5	T13	159	167	176	178	236	14.2
	"	T14	147	158	173	180	238	12.0
		AV	153	163	175	179	237	13.1
	5 + 30	T16	149	158	173	177	216	12.9
	"	T17	156	167	179	182	215	13.1
		AV	153	163	176	180	216	13.0

TABLE 3 (contd)

Maraging steel

(c) DTD 5212

Temperature ^{o}C	Time sec	Sample No.	0.1% proof stress MNm^{-2}	0.2% proof stress MNm^{-2}	0.5% proof stress MNm^{-2}	UTS slow ($0.0042\ sec^{-1}$) Strain rate MNm^{-2}	UTS fast ($0.042\ sec^{-1}$) Strain rate MNm^{-2}	Elongation %
R.T.		MS6	1746	1774	1801	1805	1813	9.2
		MS7	1757	1776	1796	1796	1808	8.8
		AV	1752	1775	1799	1801	1811	9.0
300	5	MS32	1403	1415	1427	1423	1427	7.1
	"	MS35	1469	1485	1489	1493	1493	8.0
		AV	1436	1450	1458	1458	1460	7.6
	5 + 30	MS33	1460	1468	1484	1484	1484	7.9
	"	MS34	1404	1412	1428	1424	1428	7.5
		AV	1432	1440	1456	1456	1456	7.7
500	5	MS16	1098	1113	1132	1133	1146	8.6
	"	MS18	1117	1126	1142	1142	1153	7.3
		AV	1108	1120	1137	1138	1150	8.0
	5 + 30	MS19	1156	1173	1190	1190		7.2
	"	MS37	1083	1096	1113	1118		10.3
		AV	1119	1134	1151	1154		8.7
700	5	MS25	353	373	402	415	456	14.2
	"	MS26	350	368	400	424	460	13.9
		AV	352	371	401	420	458	14.1
	5 + 30	MS27	376	392	411	447	447	13.4
	"	MS29	371	391	416	462	462	13.9
		AV	374	392	414	455	455	13.7

TABLE 3 (contd)

(d) RPE 1090 (G 125)

Temperature ^{o}C	Time sec	Sample No.	0.1% proof stress MNm^{-2}	0.2% proof stress MNm^{-2}	0.5% proof stress MNm^{-2}	UTS slow ($0.0042\ sec^{-1}$) Strain rate MNm^{-2}	UTS fast ($0.042\ sec^{-1}$) Strain rate MNm^{-2}	Elongation %
R.T.		MS17	2084	2087	2095	2095	2107	7.4
		MS18	2065	2077	2089	2096	2108	7.1
		AV	2075	2082	2092	2096	2108	7.3
300	5	MS14	1757	1765	1765	1773		6.6
	"	MS31	1765	1765	1761	1765		6.6
		AV	1761	1765	1763	1769		6.6
	5 + 30	MS15	1745	1753	1753	1756		6.7
	"	MS32	1759	1767	1767	1771		6.9
		AV	1752	1760	1760	1764		6.8
500	5	MS23	1428	1432	1416	1432		6.0
	"	MS24	1412	1416	1404	1416		6.4
		AV	1420	1424	1410	1424		6.2
	5 + 30	MS25	1392	1400	1392	1400		6.2
	"	MS26	1360	1371	1363	1375		6.6
		AV	1376	1386	1378	1388		6.4
700	5	MS27	369	389	412	424	453	13.6
	"	MS28	365	383	407	421	459	13.7
		AV	367	386	410	423	456	13.7
	5 + 30	MS29	373	389	407	414	443	12.4
	"	MS30	374	389	407	413	445	12.4
		AV	374	389	407	414	444	12.4

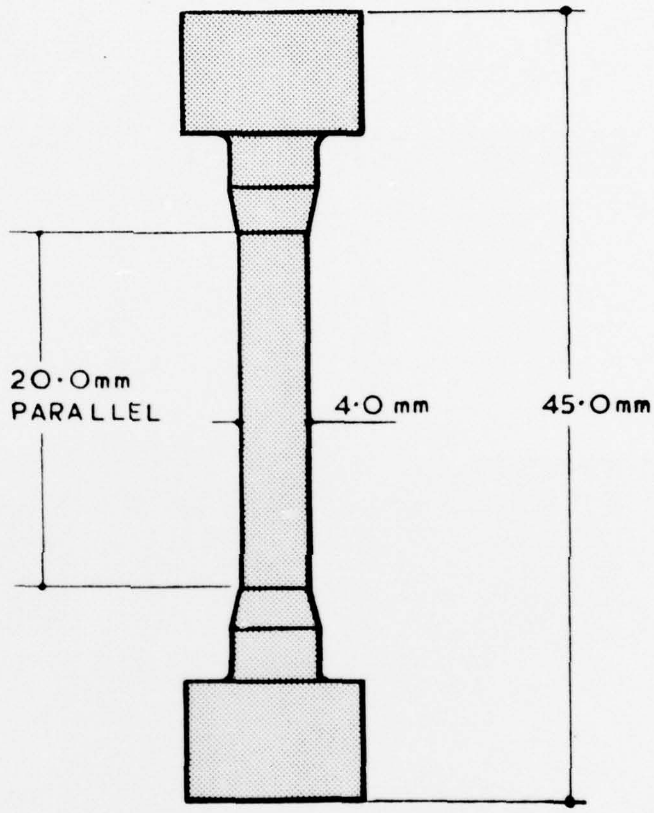

FIG.1 CYLINDRICAL TEST PIECE

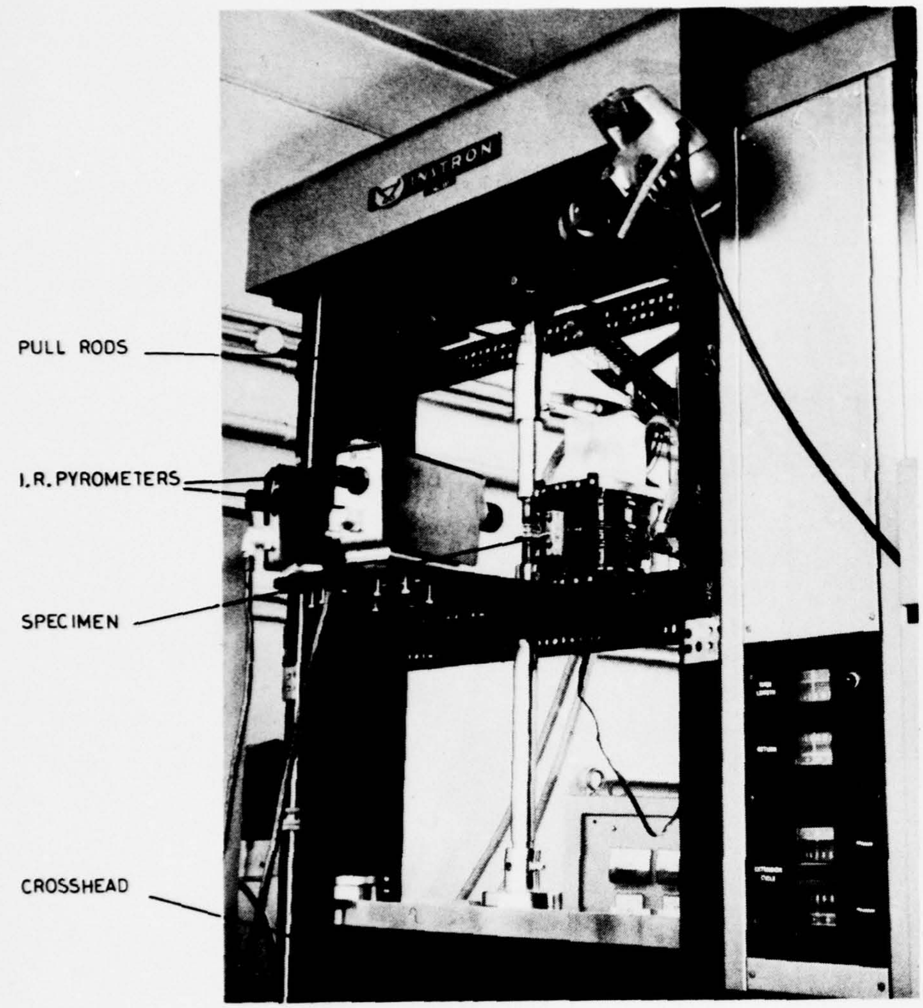

FIG.2 TEST ASSEMBLY

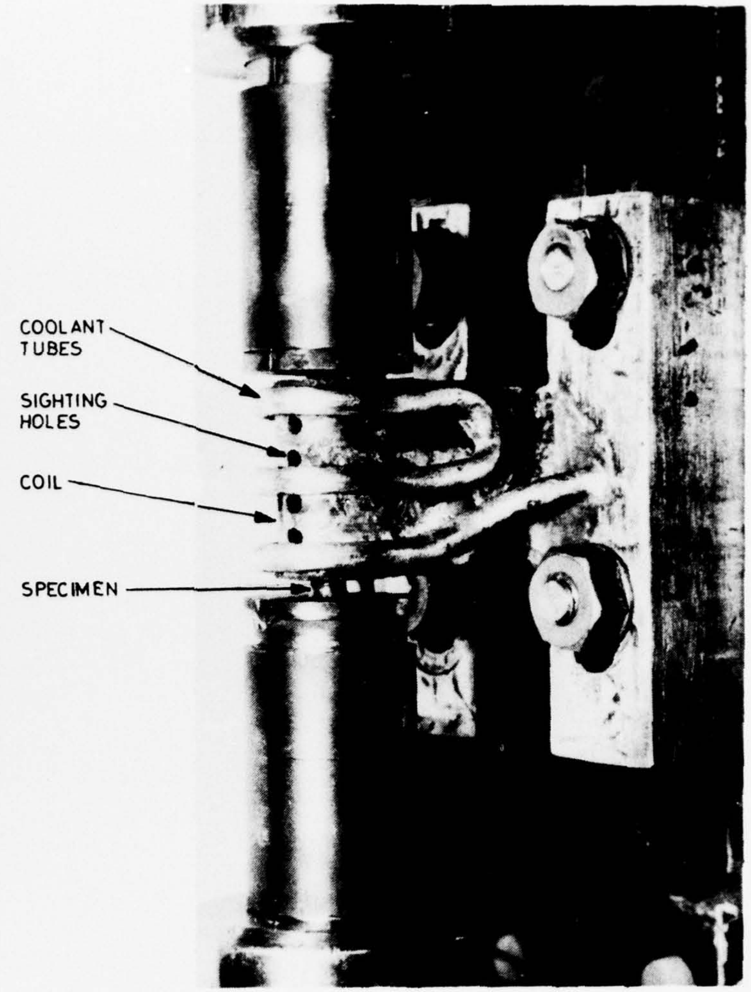

FIG.3 SPECIMEN IN POSITION IN ONE-TURN STRIP COIL

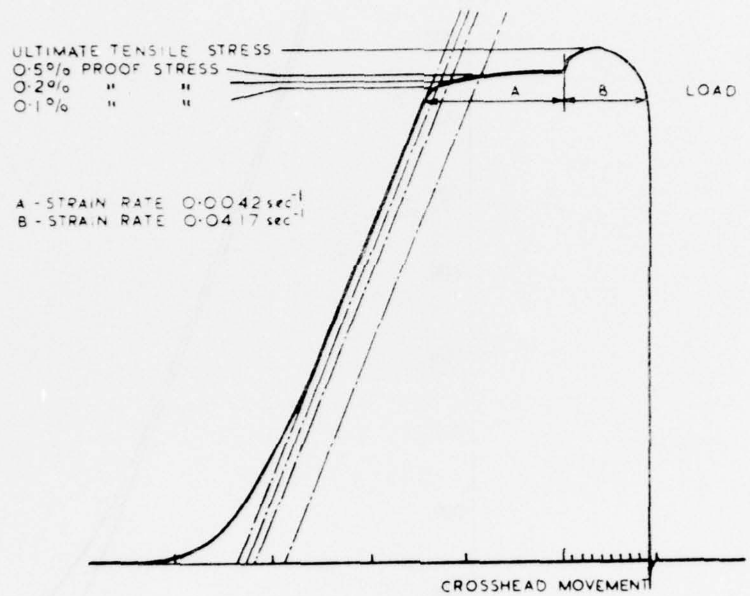

FIG. 4 EXPERIMENTAL LOAD/EXTENSION DIAGRAM

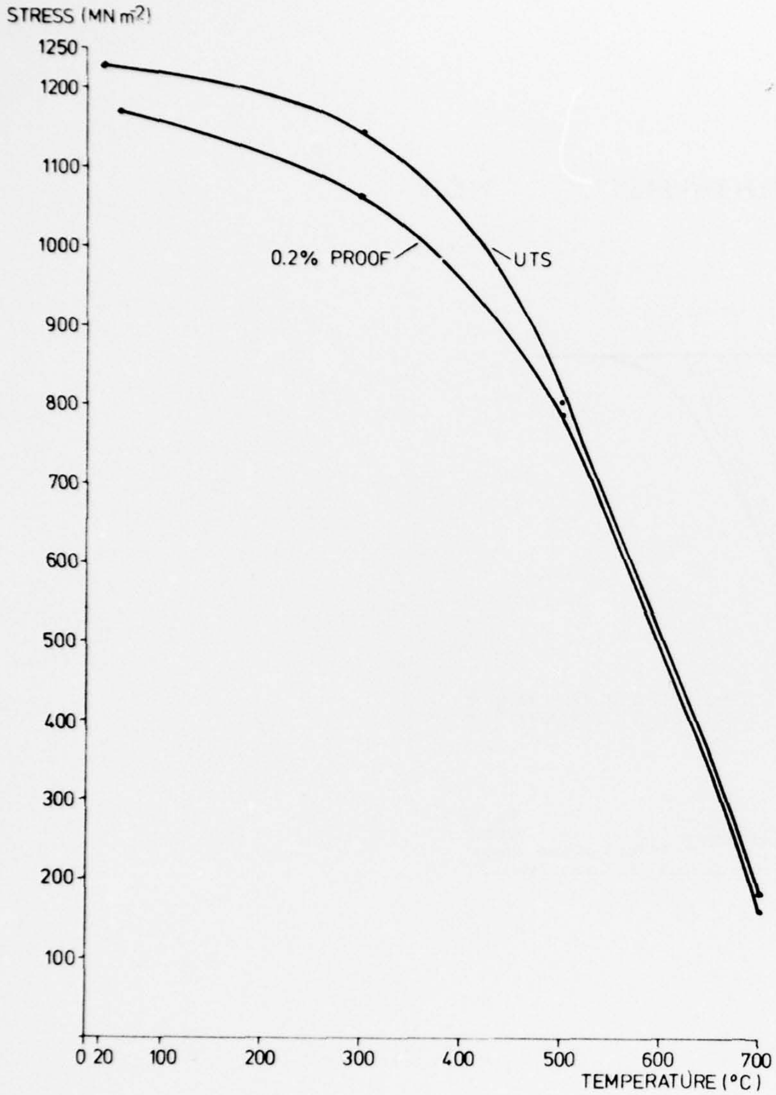

FIG. 5(a) VARIATION OF UTS AND 0.2% PROOF STRESS WITH TEMPERATURE. RS130 LONGITUDINAL SPECIMENS TESTED AT $4{\cdot}2\times10^{-3}$ SEC^{-1} STRAIN RATE, IMMEDIATELY UPON ATTAINING TEMPERATURE

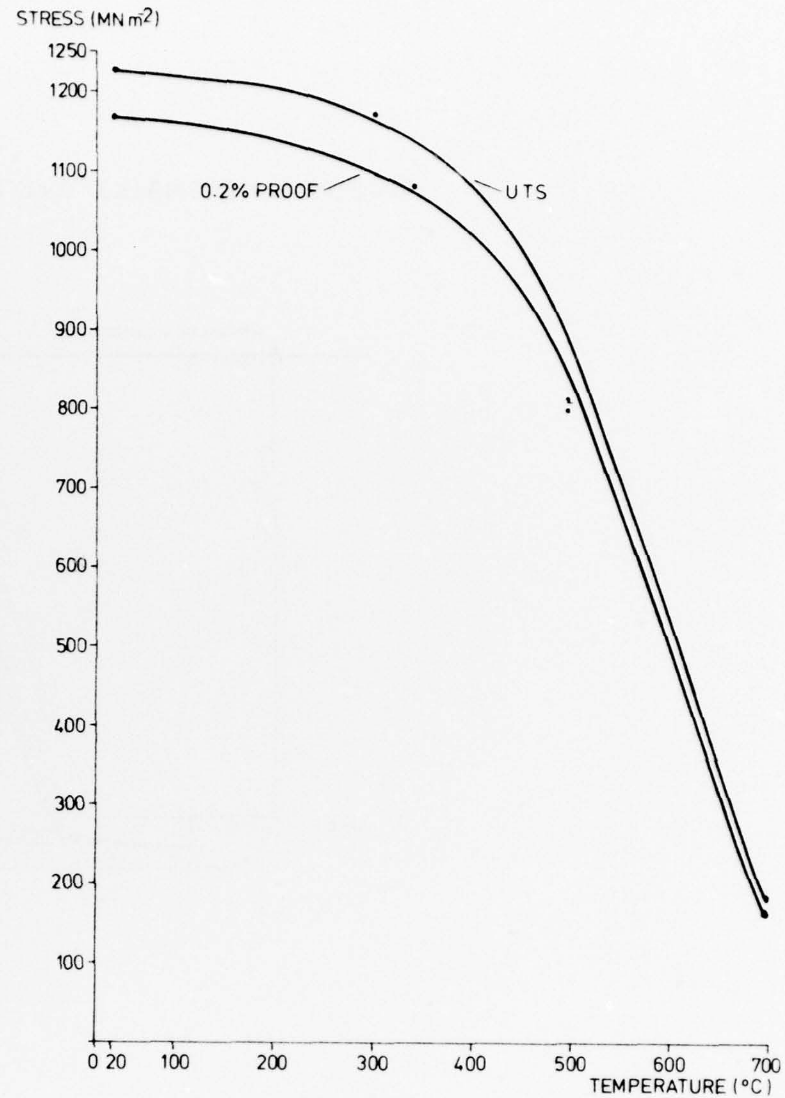

FIG. 5(b) VARIATION OF U.T.S AND 0.2% PROOF STRESS WITH TEMPERATURE. RS130 LONGITUDINAL SPECIMENS TESTED AT $4{\cdot}2\times10^{-3}$ SEC^{-1} STRAIN RATE, 30 SEC AFTER ATTAINING TEMPERATURE

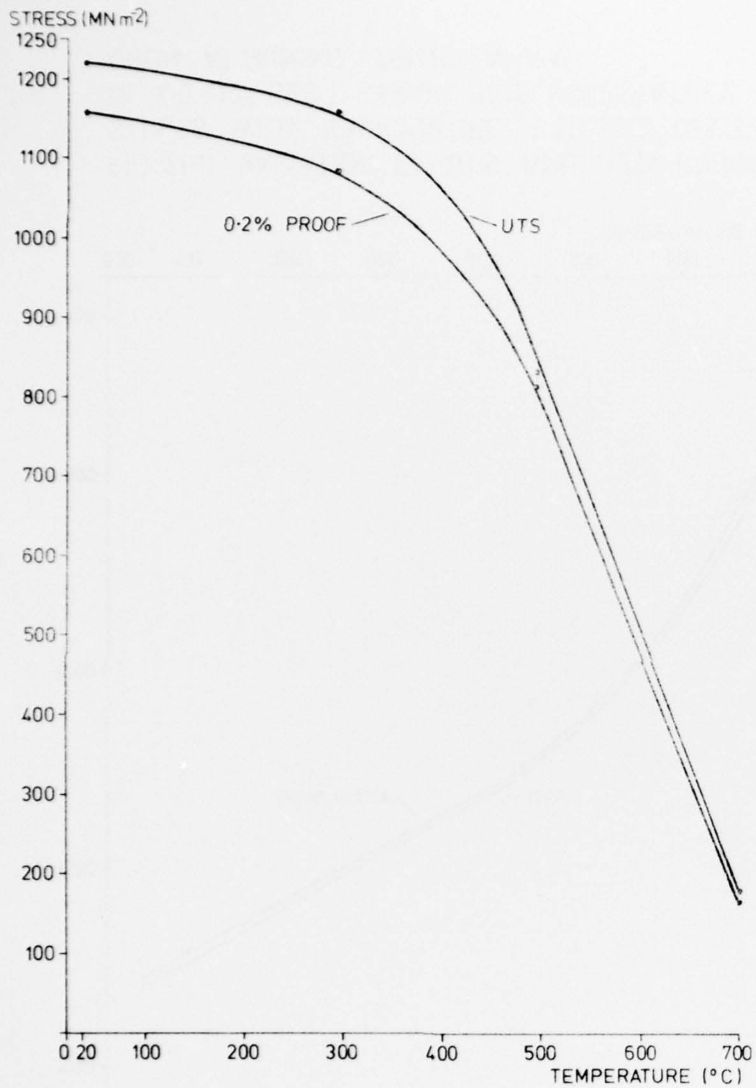

FIG. 6(a) VARIATION OF UTS AND 0·2% PROOF STRESS WITH TEMPERATURE. RS130 TRANSVERSE SPECIMENS TESTED AT $4{\cdot}2\times10^{-3}$ SEC^{-1} STRAIN RATE, IMMEDIATELY UPON ATTAINING TEMPERATURE

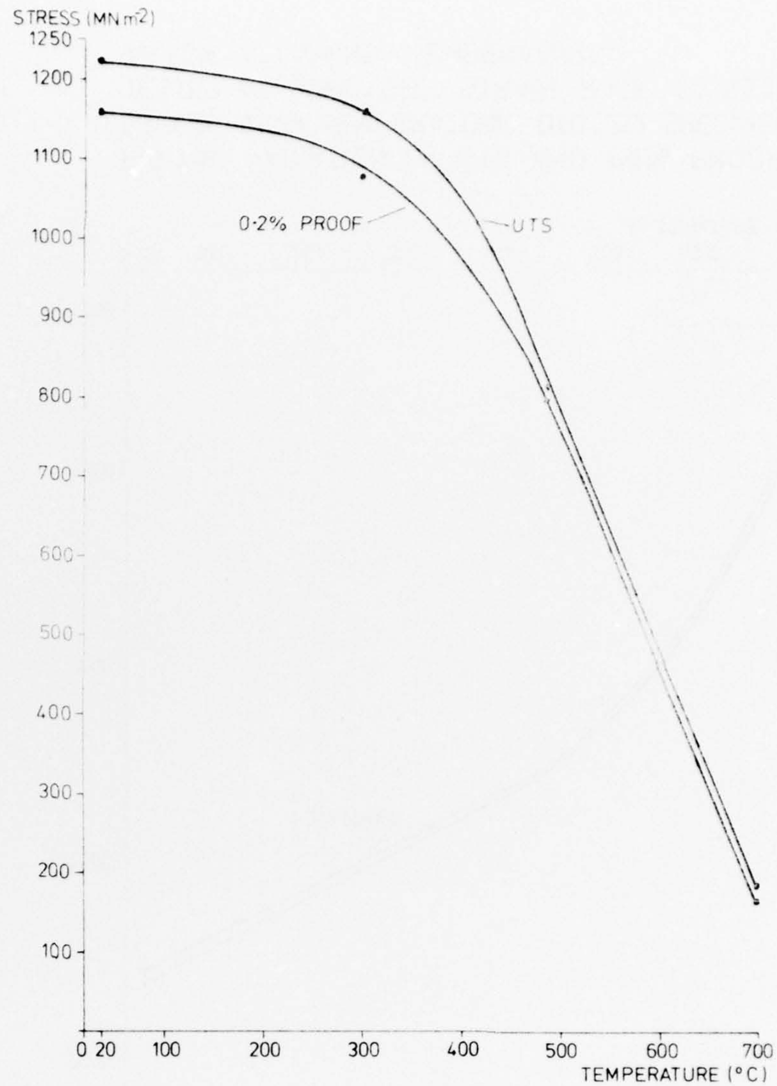

FIG. 6(b) VARIATION OF UTS AND 0·2% PROOF STRESS WITH TEMPERATURE. RS130 TRANSVERSE SPECIMENS TESTED AT $4{\cdot}2\times10^{-3}$ SEC^{-1} STRAIN RATE 30 SEC AFTER ATTAINING TEMPERATURE

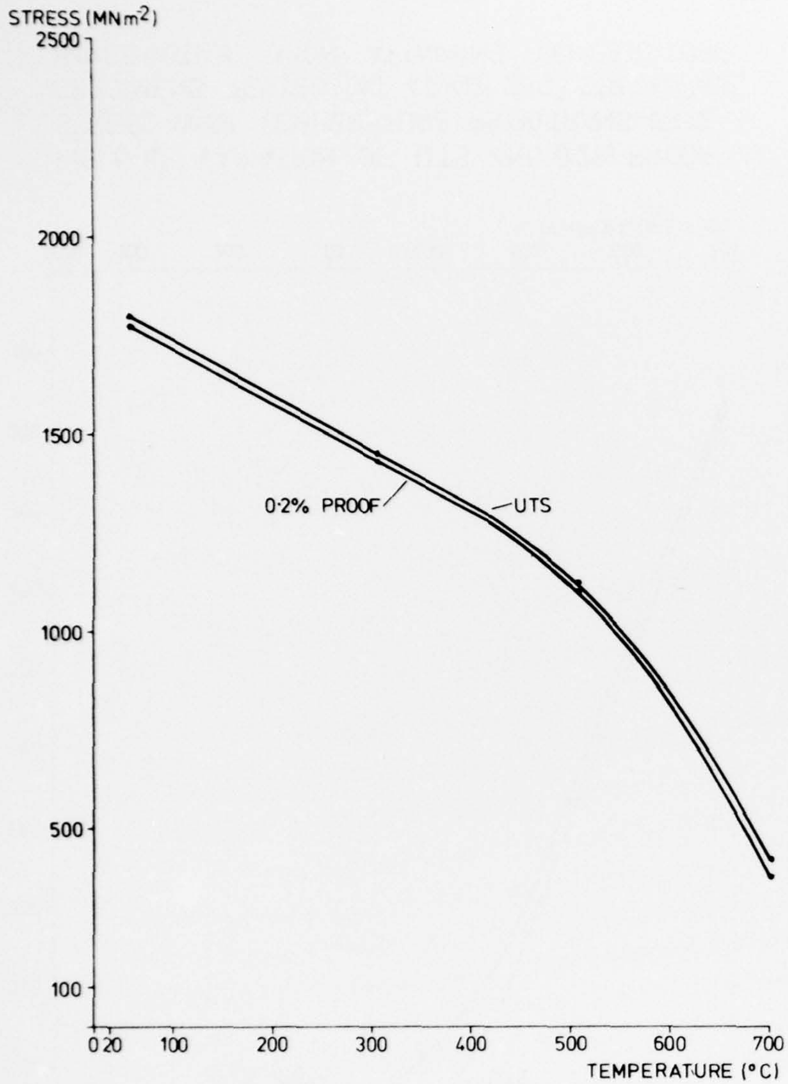

FIG 7(a) VARIATION OF UTS AND 0·2% PROOF STRESS WITH TEMPERATURE. DTD 5212 TESTED AT $4 \cdot 2 \times 10^{-3}$ SEC^{-1} STRAIN RATE IMMEDIATELY UPON ATTAINING TEMPERATURE

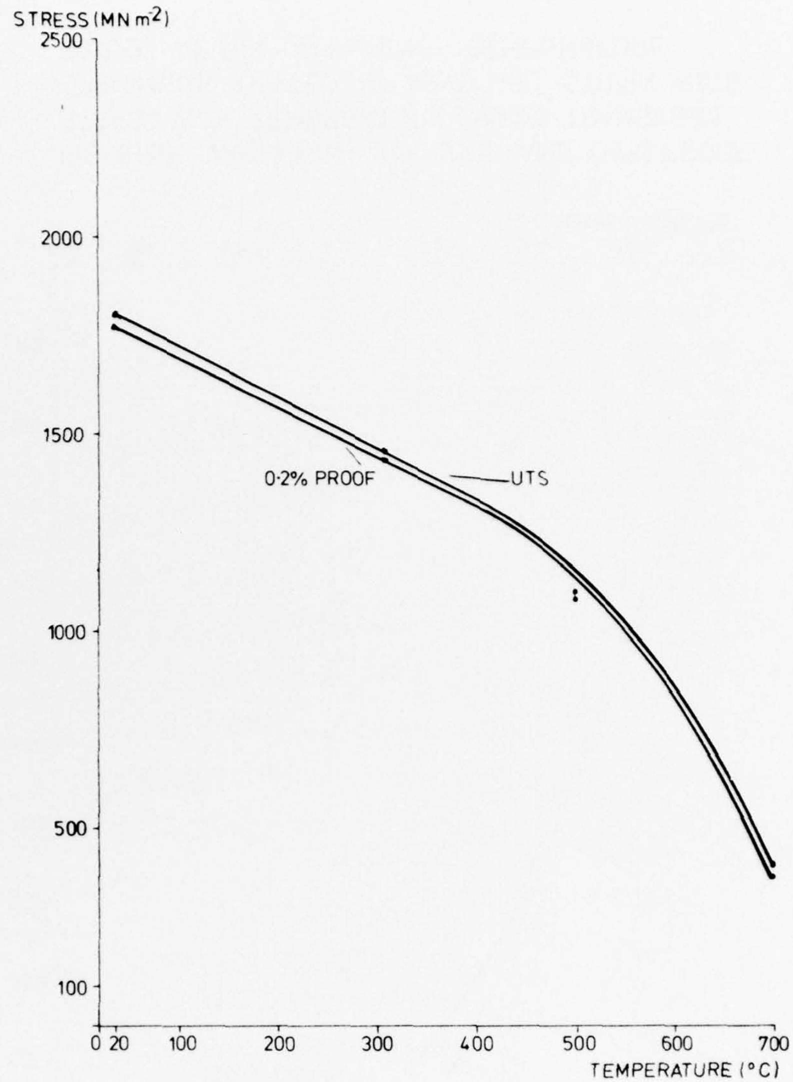

FIG 7(b) VARIATION OF UTS AND 0·2% PROOF STRESS WITH TEMPERATURE. DTD 5212 SPECIMENS TESTED AT $4 \cdot 2 \times 10^{-3}$ SEC^{-1} STRAIN RATE 30 SEC AFTER ATTAINING TEMPERATURE

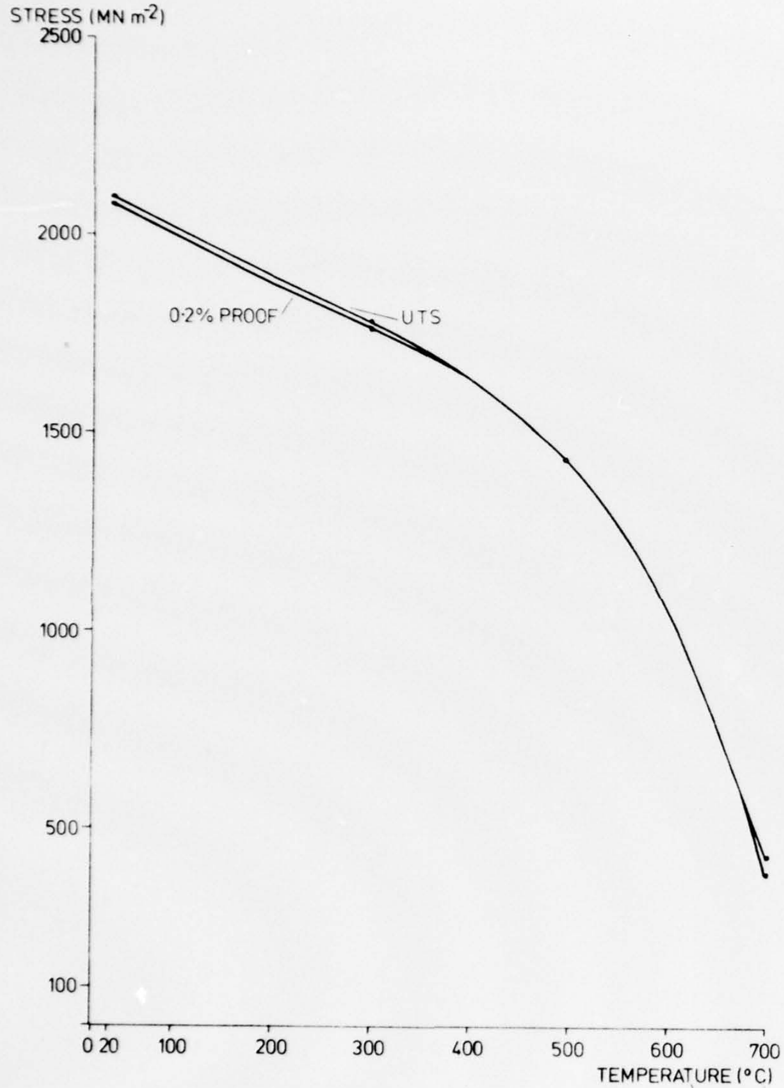

FIG. 8(a) VARIATION OF UTS AND 0·2% PROOF STRESS WITH TEMPERATURE. G125 SPECIMENS TESTED AT $4{\cdot}2\times10^{-3}$ STRAIN RATE IMMEDIATELY UPON ATTAINING TEMPERATURE

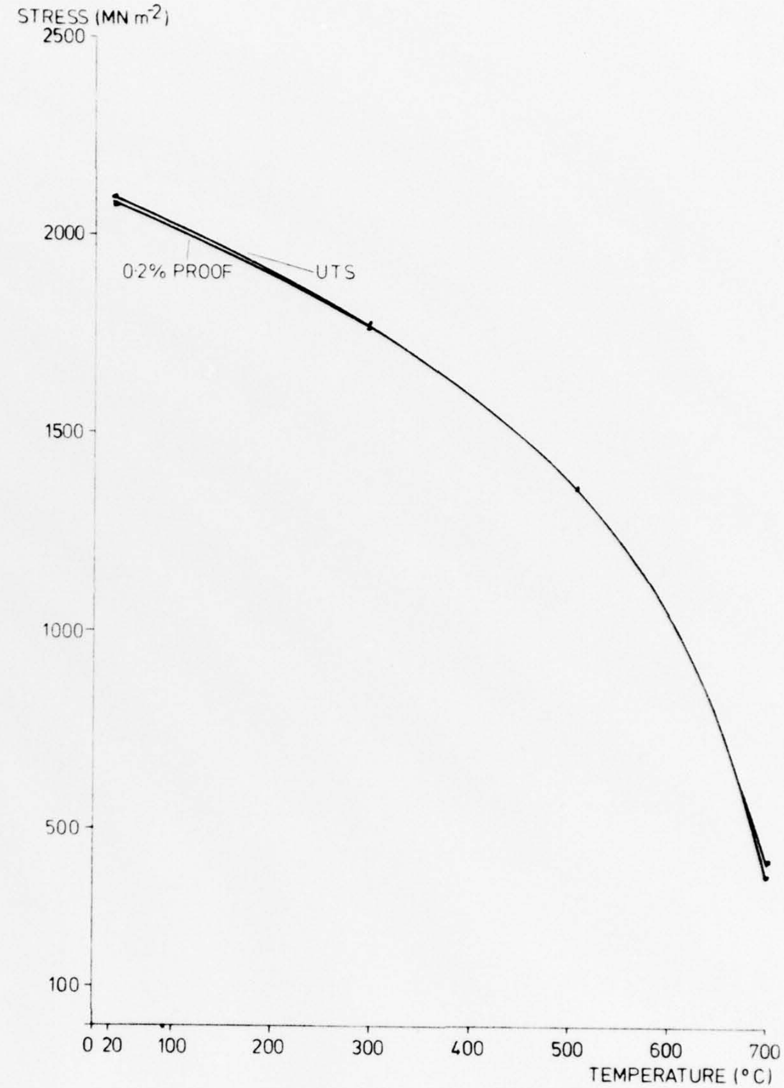

FIG. 8(b) VARIATION OF UTS AND 0·2% PROOF STRESS WITH TEMPERATURE. G125 SPECIMENS TESTED AT $4{\cdot}2\times10^{-3}\,SEC^{-1}$ STRAIN RATE 30 SEC AFTER ATTAINING TEMPERATURE

DOCUMENT CONTROL SHEET

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7. Title

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7a. Title in Foreign Language (in the case of translations)

7b. Presented at (for conference papers). Title, place and date of conference

8. Author 1, Surname, initials	9a Author 2	9b Authors 3, 4...	10. Date	pp	ref
Ramsden, G.R.	Herrick, D.A.R.		6. 1976	24	3

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15. Distribution statement

15. Descriptors (or keywords)

Alloy steels; Rocket motor cases; Mechanical properties; Aerodynamic heating; Proof stress; Ultimate tensile strength.

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Abstract

The report investigates the effect of simulated aerodynamic heating on three high strength steels [RS 131, DTD 5212 and RPE 1090 (G125)] at temperatures up to 700°C, attained in 5 seconds.